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Technological archetypes for a UK energy system transition

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Working Paper 2014/2

Realising Transition Pathways

Whole systems analysis for a UK more electric low carbon energy future



Realising Transition Pathways

'Realising Transition Pathways' (RTP) is a UK Consortium of engineers, social scientists and policy analysts. The consortium is managed by Professor Geoffrey Hammond of the University of Bath and Professor Peter Pearson of Cardiff University (Co-Leaders). It includes research teams from nine British university institutions: the Universities of Bath, Cardiff, East Anglia, Leeds, Loughborough, Strathclyde, and Surrey, as well as Imperial College London and University College London. The RTP Project [www.realisingtransitionpathways.org.uk] commenced in May 2012 and is sponsored by the 'Engineering and Physical Sciences Research Council' (EPSRC: Grant EP/K005316/1). It is a renewal and development of the earlier 'Transition Pathways' (TP) project, which was initially established in 2008 with the joint sponsorship of E.ON UK (the electricity generator) and the EPSRC. This project addressed the challenge of the so-called energy 'trilemma': the simultaneous delivery of low carbon, secure, and affordable energy services for the electricity sector. It developed and applied a variety of tools and approaches to analyse the technical feasibility, environmental impacts, economic consequences, and social acceptability of three 'transition pathways' towards a UK low carbon electricity system. These pathways explore the roles of market, government and civil society actors in the governance of a low carbon energy transition.

The research within the RTP Project seeks to explore further the constraints and opportunities in realising a low carbon UK energy sector, including those stemming from European developments. This project includes studies on the horizon scanning of innovative energy technologies over the period to 2050, the feasibility of demand responses, uncertainties in economic analysis, the estimation of investment costs of the different pathways, and the implications of markets for investment decisions about energy technologies. Further work is being undertaken on conceptualising, mapping and analysing 'actor dynamics' in the contemporary UK electricity sector, historical transitions and case studies, integrated energy networks modelling and evaluation, and 'whole systems' energy and environmental appraisal of low carbon technologies and pathways. The consortium is also developing their initial work on branching points on pathways, in order to identify and explore other potential branching points on the core transition pathways.

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This document has been prepared to enable results of on-going RTP work to be made rapidly available. It has not necessarily been subject to review and approval, and may not have the authority of a full Research Report or published paper.

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2 Introduction

The Distributing Power report (RTP Engine Room, 2015), recently published by the Realising Transitions Pathway consortium, examines the social, political and technical feasibility of the socio-technical scenario '*Thousand Flowers*'. The Thousand Flowers pathway describes the evolution to a highly distributed energy future where more than 50% of electrical demand is met by distributed generation in 2050. This working paper is an addendum to the Distributing Power report and aims to describe the generation components of such an energy future.

In this working paper we describe the individual technological archetypes that have been developed for the key technologies in the Thousand Flowers pathway. These archetypes demonstrate the importance of each technology and how they might manifest in a UK civic energy system. Each technology is explored in isolation, allowing their various aspects to be investigated against the pathway and its current timeline. The technological feasibility of the main assumptions is established, allowing potential issues to be identified. Treating each technology individually within this working paper enabled a greater systemic view to be achieved in the Distributing Power report. The technological archetypes herein discuss technological, social, and economic drivers and barriers to development, to ensure that the whole scope of the transition is considered on a technology by technology basis.

The development of the following technological archetypes was a valuable and beneficial process as it allowed:

- The initial assumptions to be teased out of the narrative text and quantitative data;
- Testing and investigating the qualitative and quantitative pathway descriptions;
- Visualisation of the pathway; and

The pinpointing of weaker elements which were then developed in greater detail in order to strengthen their feasibility in this future.

The archetypes follow a common format; first, the importance of the technology to the pathway is identified, determining the significance of the specific technologies to the pathway. Archetypes of installations are then described alongside discussion of drivers for technologies, fuel supply, sources of technologies and expertise, geographic location, issues and barriers, and finally their costs and benefits are examined. Finally, the system issues and management of this future energy system are discussed.

3 Combined Heat and Power

3.1 Importance to the pathway

Large-scale, community-scale and micro-CHPs are of considerable importance in the Thousand Flowers pathway. As well as supplying a total of over 41 per cent (134.6TWh/year) of total electricity demand they are responsible for heating 60 per cent of our homes by 2050 (Barnacle, 2013 and Barton, 2013b). These CHPs are large-scale, community-scale and micro-scale installations and are powered by renewable fuels using a range of technologies: fuel cells, Stirling engines, gas turbines, steam turbines, reciprocating engines and combined cycles of different conversion technologies.

3.2 Drivers for CHPs

CHPs have several advantages over other renewable generators in terms of security of supply. First, CHPs depend on the gas grid that is considered more reliable than the electrical grid due to increased storage capability through linepacking. Second, CHPs serve islanded heat networks but by default are still connected to the electricity grid. Such design guarantees the baseload electricity supply to consumers in the case of blackouts or intermittent generation. Last, CHPs offer voltage and frequency control and regulation capability to the grid as they move away from today's passive distributed generation (DG) (Lopes, 2006). If heat led, however, they offer only as much electricity as the heat demand and storage allows.

3.3 Fuel supply

CHPs can have a flexible fuel supply and take a variety of fuel types. In the Thousand Flowers pathway the electricity generated by CHPs is met by the following technologies which imply that the dominant fuel source is biogas sourced from anaerobic digestion and biomass gasification¹.

- 5.3 per cent Stirling engines (micro-CHPs);
- 29.3 per cent fuel cell micro-CHPs;
- 48.3 per cent community-scale biogas CHPs;
- 17.1 per cent large-scale biomass CHPs.

Solid biofuels are not used within the Thousand Flowers pathway due to issues relating to maintenance (removal of ash), storage and delivery of fuel (woodchips or pellets are labour-intensive and relatively difficult to deliver in the urban environment) and air quality (difficulty meeting local air quality regulations in towns and cities). Synthetic natural gas (SNG) can be made from biomass by gasification or anaerobic digestion and gas-fired CHPs can be built ahead of the establishment of a bio-synthetic gas supply chain or even a biomass supply chain.

Natural gas will fuel all of the Stirling engine micro-CHPs and a proportion of the fuel cell micro-CHPs also. This comes with major security of supply implications as the UK has become more reliant on imported gas in the past decade. The development of UK shale gas may likely relieve much of these concerns but with varying environmental implications. Hydrogen will fuel the remainder of fuel cells and the level of penetration of fuel cell CHPs will depend on the development of the wider hydrogen infrastructure in the UK. Since the fuel cells can be run on both natural gas and hydrogen there is room for a transition to the less impactful fuel once the domestic market has caught up. A move

¹ The fuel sources from the UK and abroad are further discussed in the section on the biomass archetype.

from the current dominant pathway of hydrogen production by steam reforming of hydrocarbons to electrolysis powered by renewables must first occur.

3.4 Sources and technology expertise

The UK's technology expertise with CHPs is relatively underdeveloped with learning from EU counterparts, such as Denmark (where 60 per cent of the population rely on district heating systems) (DECC, 2014b), Sweden or Finland needed. Large-scale CHPs are currently available, but there is likely not sufficient expertise in the UK for the aspired level of manufacturing and installation. The hardware and engineering knowledge for installing and maintaining the CHPs will likely need to come from abroad with a manufacturing opportunity within the UK that could help renew domestic manufacturing industry. Upskilling in the construction industry would also be required for integration of CHPs in new dwellings and industrial developments. This process could benefit from best practice examples early on in the transition process that would foster wider learning.

For a long time there have been expectations for a reliable system based on fuel cells. The UK already has a strong chemistry expertise in the field of fuel cells (UKHFCA, 2014) and while there is some progress in this field the pace is not yet at the necessary level.

3.5 Geographical location

CHPs are not dependent on specific location for solid fuels, but do require a connection to the gas grid for gas-fuelled technologies. The spatial density and patterns of heat use determine the technical and economic feasibility of CHPs (Mayor of London, 2014). Industrial sites, swimming pools, and houses with large heat requirements are more appropriate for small-scale and micro-CHPs. For large- and community-scale CHPs, densely populated areas will be necessary for installation of district heating grids.

3.6 Connection

Community-scale CHPs can be installed in new build housing developments, so that community district heating systems are fully integrated, similar to the Danish model, with additional land needing to be set aside for the CHP unit and storage facilities. Large-scale, community-scale and micro-scale gas fuelled CHPs would be connected to the natural gas or biogas grid and this would allow storage facilities to be forgone.

Examples of the community scale systems could be:

- 300 houses, 0.6MW heat and 0.3MW electricity;
- 1000 houses, 2MW heat and 1MW electricity; and
- 5000 houses, 10MW heat and 5MW electricity.

Energy efficient houses cause both weaknesses and advantages for such a system. Their demand may be very low and this will negatively affect the technical and economic feasibility of district heating grid or CHPs units themselves. At the same time, all day long 'smoothing out' of the heat demand could be expected.

3.7 Build rates of CHPs

The average net build rate of CHPs with this pathway will be almost 3GWe per year between 2015 and 2020, declining thereafter. This contrasts with the build rate in 2012 of only 433MWe and a net

installation rate (subtracting old CHP schemes retired or no longer defined as CHPs) of only 166MWe (BERR, 2013) meaning a very fast scale up of installation is required. If the average scheme size remains the same as in 2012 (0.31MWe) (BERR, 2013), then 3GWe installed each year would represent approximately 10,000 new schemes being installed compared to around 400,000 solar PV installations per year in 2012. The build rate of CHP is therefore challenging but not impossible when comparing with that of PV. It will require concerted political will, incentives e.g. the renewable heat incentive (RHI) and will require a long-term plan for biomass conversion into fuels suitable for CHP.

3.8 Issues and barriers

In order to motivate communities to build CHPs, financial instruments are necessary, as well as other programmes, to encourage community co-operation.

The drivers for the community-scale CHPs with district heating could be that less area is needed in the houses for heating infrastructure (where the owners would prefer the road dug up for a few weeks rather than a room with heating equipment) and, additionally, the reduced maintenance inconvenience in homes. However, issues around who is responsible for the CHP plant or deliveries of biomass when ownership is shared, and administrative issues relating to setting up community companies with individual households owning shares in the scheme, all need to be cleared up before installations are made.

3.9 Cost and benefits

As the electricity grid becomes decarbonised, investment in biogas CHPs will lock the UK into a higher carbon system than an alternative system dependent on electricity. This will result in higher carbon emissions and air pollution. However, these electricity-based alternatives may not have the same demand response capabilities as CHPs. Fuel cell micro-CHPs, however, can contribute to lower emissions and pollution, dependent on the source of hydrogen.

4 Biomass Generation

4.1 Importance to the pathway

In 2050 there is 1.50GW of biomass fuelled electricity generation capacity (not including biomass fuelled CHP units), generating 2.37TWh/year². Biomass is the smallest contributor, providing 0.72% of the total electrical supply within the pathway but plays a key role as a dispatchable generator to help support the large amount of intermittent wind power.

4.2 Sourcing of biomass

Biomass is used in the form of pellets, wood chips, wet biomass, and biomass from wet and dry waste including municipal waste, landfill gas, sewage sludge digestion, animal, and plant biomass. Up to 31 per cent of the land available domestically for growing bio-crops is in the South West region (NNFCC, 2012). On the other hand, the South East has the largest amount of forestry resource for sourcing woody biomass (Woodcock, 2013). There is a wide variation in domestic biomass availability estimates in the literature (AEA, 2011) and to some extent it could be argued that once deployment barriers to technology are overcome, the domestic biomass market will follow. Similarly, land use study results vary greatly (UKERC, 2011), but there is room for significant growth dependent on the crop yields and other factors.

Imported biomass may be a potential bottleneck because of competition from other international markets. Studies suggest that imports will grow up to 2030 but, due to international demand, will begin to decrease again out to 2050 (DECC, 2013). The following issues need to be considered:

- Energy density versus transport costs. Biomass has a low energy density because of its physical form and moisture content. This makes it inconvenient and inefficient for storage and adds to transport costs. To increase its energy density, biomass may need to be processed, which further increases energy cost.
- Sustainability assessment is essential as there is a need to ensure continuity of supply and ensure that biomass reserves are replenished – difficult to monitor internationally (DECC, 2012).
- Biomass supply will have to compete for land with transport fuel and food sectors, which cause potential constraints.

4.3 Sources of technology and expertise

Biomass-based power generation technology is relatively mature, however, due to the large demand of resources, expertise for guaranteeing the security of supply is required. The UK has gained significant experience in using biomass for co-firing as well as strengths in crop science but there is room to further develop expertise through research (Welfle, 2014). Finally, due to the expectations of the negative carbon emissions from biomass CCS (IEA, 2011), unlocking the potential of CCS seems crucial to the growth of biomass. The UK is currently one of the leaders in CCS technology although the success of CCS is highly uncertain.

² Supply side spreadsheet

4.4 Geographical location

As mentioned above, a large majority of biomass fuel for power generation will need to be imported into the UK. Domestic resources are also available but are highly dispersed (Welfle, 2014). Therefore, biomass plants may be located close to the shore to limit overland transportation costs and associated emissions. However, the location of biomass plants with CCS would most likely not be determined by the point of supply but by the geography of carbon storage options.

4.5 Domestic scale installations for heat production

All biomass burners and boilers involve extra work and inconvenience compared to a gas boiler. All require ash removal, some on a weekly basis but daily in the case of a log burner, without which performance will deteriorate and may cause the boiler to break down (Verma, 2011). All occupy more space than a gas boiler and also require dry storage space for the fuel with accessibility for delivery. Chimney sweeping is required twice a year and building regulations / HETAS approval (Dept. of Communities and Local Government, 2013b) is required to ensure safe fitting.

Efficiency depends upon how the domestic installations are used, e.g. if a wood-burner with a back-boiler is used, then the operating efficiency of the stove reduces. On average, the efficiency is lower than that of natural gas boilers or heat pumps.

4.5.1 Logs

Logs burners are very labour-intensive requiring manual feeding and daily ash emptying. They may not be suitable for houses that are not occupied during the day as they lack the controllability of gas boilers. The best locations for log burners are rural areas close to the source of wood.

4.5.2 Woodchips

Wood chips are cheap and abundant, however are not as efficient as wood pellets. Their low energy density makes them less suitable for domestic use as it requires a substantial storage provision, usually beyond the capabilities of a typical domestic dwelling (FCI, 2014).

4.5.3 Pellets

Wood pellets are suitable for smaller, household boilers, and are also available with automatic feed and control, but the pellets have to be industrially produced.

4.5.4 Build rate of domestic-scale installations

The biggest challenges to all biomass boilers are the availability of logs, woodchips, and pellets, and local air quality standards (Clean Air Act, 1993), making them unsuitable for widespread use in urban areas. The build rate of biomass boilers does not appear to be an issue in the Thousand Flowers pathways since new solid fuelled boilers are not going to be built.

4.5.5 Grid connection of domestic scale installations

Boilers do not consume or use significant amounts of electricity and therefore do not have grid connection problems. At the same time, they rely on the availability of the grid to run auxiliary and control systems such as biomass feed augers and water pumps.

4.5.6 Sustainability

Biomass is only completely carbon-neutral if it is locally sourced, requiring no fossil fuel for transportation or processing, and if new biomass is planted and grown at the same rate as demand. It must be noted that although biomass may be carbon-neutral over its life cycle, CO₂ is emitted as it is consumed.

5 Photovoltaics (PV)

5.1 Importance to the pathway

By 2050 there is 16.2GW of PV generation capacity producing 15.8TWh annually, equivalent to 4.8 per cent of generation. Currently in the UK only 13 per cent of PV installations are non-domestic. If all of the 16.2GW were to consist of domestic installations, and assuming an average capacity of 3kW, then there would be 5.4 million domestic installations. However, indicative figures for installations of PV by 2050 within the Thousand Flowers pathway would be (by installed capacity): 60 per cent domestic, 30 per cent industrial/commercial rooftops and 10 per cent ground-mounted farms.

5.2 Resource

Southern England receives similar total solar irradiation (1200kWh/m²/year) to that in Germany (IRENA, 2014) where PV use is much greater. The total area of relatively unshaded, south-facing domestic rooftops is in the order of 250 million square metres (10m² per dwelling), able to support a PV capacity of about 35GW. Non-domestic rooftops might add a similar amount. If, in addition, just 5 per cent of UK land area (12,000km²) were used for a combination of PV and grazing, with 25 per cent PV coverage, then ground-mount systems could add a further 500GW. This would be more than enough for all the UK's electricity requirements as an annual total.

However, resource varies greatly between seasons, with up to six times more solar radiation in the summer than in winter (Burgess, 2009). Therefore, PV installations are likely to be limited by the ability of the electricity system to cope with the seasonal and daily variation and the ability to make use of them at times of peak supply.

5.3 Sources of technology, supply chain, and expertise

The supply chain and expertise for installation is already well established following the boom years of 2011 and 2012. However, the UK currently relies on PV modules manufactured abroad cheaply.

The bulk materials used in today's silicon PV cells are silicon and non-precious metals but smaller amounts of indium, silver, and gallium are also used (REF.com, 2014). Growth of PV might be constrained unless alternatives are found to some of the rarer elements. Better regulation is also required to ensure good end of life treatment with precious metal recovery.

5.4 Geographical location

Regionally, there is a variation in solar irradiation of between 900kWh/m²/year in the north to 1,250 kWh/m²/year in the south west (RenSMART, 2014). Suitable rooftops are mainly located in the south of the UK, since that is where population density is highest. Areas close to the coast also appear to enjoy higher solar irradiance (Met Office, 2014).

The regional differences in solar irradiance are, however, partially offset by temperature as efficiency of PVs reduces with increased temperature (Shockley, 1961). Scotland therefore benefits from its cooler weather alongside longer day length in summer. The geographical differences in PV performance are not as important as proximity to electricity demand to minimise grid reinforcement requirements.

Urban Single Flower - Derby SHINE-ZC

Technologies: Solar PV, air source heat pump (ASHP), solar thermal, biofuel CHP



Shine-ZC (Source: www.shine-zc.co.uk)

The SHINE-ZC project (Sustainable Housing Innovation Network of Excellence – Zero Carbon) is a new build, compact, affordable housing development designed to meet the code for sustainable homes (CSH) level 6 requirements. The project met the demands for CSH level 6 by integrating renewable technologies with a highly-insulated, airtight construction design using mechanical ventilation with heat recovery (MVHE). The small site made best use of limited roof space for solar PV and solar thermal technologies, integrating these with CHP and ASHP. Overall, the heating load of the building was reduced to less than half that of a conventional building, contributing to its low-carbon, affordable housing status. The project demonstrated that building design and deployment of renewable energy technologies can achieve very low carbon energy provision on a compact site.

Within the Thousand Flowers pathway 11.3 million new homes will be constructed by 2050. Compact and affordable housing such as SHINE-ZC with integrated renewable technology and high levels of insulation are essential to reaching these goals.

5.5 Grid connection

New regulations for micro-generators are needed, as have been introduced in Germany (SMA, 2012) where PVs of all sizes are required to provide system services (EEG, 2014 and VDE-AR-N 4105). Energy management at the household level is being enabled in Germany – the solar inverters will perform this management task. In particular, solar inverters are enabled to provide:

- Frequency response (grid balancing and stabilisation);
- Reactive power supply (local voltage control);
- Ride-through of temporary faults;
- Partial limitation of power by remote communication when required; and
- Larger systems are required to provide phase balancing.

5.6 Build rates

In 2012, the actual UK installation rate of PV was 925MW/year (EPIA, 2013), mainly as rooftop retrofits, which already exceeds the Thousand Flowers installation rate anticipated between 2035 and 2050 of 541MW/year. In Germany, the installation rate in 2012 was an order of magnitude higher still at 7600MW/year (EPIA, 2013) and the total installed capacity was already over 32GW (peak). Therefore, build rate is not at all limited when the right incentives are in place to grow the market. Future versions of the Thousand Flowers pathway will be able to revise the PV build rate upwards, depending on whether the solar boom of 2011 and 2012 is seen as an aberration or as part of a long term trend.

5.7 Issues and barriers

5.7.1 Cost

PVs have high capital cost of purchase and installation to be borne by the householder or other investor. This has implications for mobility, in that the typical homeowner moves more frequently than the payback period (without FiT or other subsidy). Hence, the investment may not be recouped. In addition, there are risks of panel degradation, component failure, and roof repairs obstructed by PV panels. During their lifetime, panel performance has a typical degradation of 0.5-1 per cent per annum (Jordan and Kurtz, 2012). The lifespan of an inverter is 5 years, whereas for the panels it is 25 years.

Costs and FiTs are falling, however, as manufacturing is cheaper (economy of scale and new manufacturing technology) and installation costs are levelling out. Costs could be further reduced (and risk of obstructed roof repairs solved) on new build if PVs were the roofing material, saving on duplication of roof covering material. However, the PVs will get hotter than if there were an air gap behind, leading to a reduction in performance efficiency.

5.7.2 Policy

Planning regulations currently do not encourage developments to follow a layout and design of housing to enable PV installations. PV needs roof space that is not overshadowed and with the appropriate aspect i.e. a large expanse of roof facing south east, south, or south west. Also current legislation does not protect the householders' 'solar rights', i.e. neighbours might extend their property and cause over-shadowing to existing panels or prevent future installations; protection could be put in place for new housing developments.

Previous abrupt changes to the Feed in Tariff caused a surge of demand, which might have led to poor installation practices. These changes also make it difficult for the industry to plan ahead in terms of recruitment and investment.

5.7.3 Technical limitations

The electricity distribution grid needs to adapt to more installed PV (and other DG) so that wires can carry enough exported power from more houses and voltage issues are solved. The generation profile of PV does not match the electricity demand profile with its evening peak of lighting loads.

5.7.4 Efficiency

The efficiency of panels (typically 15-20 per cent) and whole system (10-18 per cent, as installed) (Fraunhofer, 2014) are nearing the theoretical maximum for the current, single-junction technology; surplus energy is converted to heat, having a negative impact on panel performance. Hybrid PV-Thermal panels do not provide the answer because the balance of electricity to heat becomes an

issue, along with the attendant problems of any combined technology i.e. if one aspect fails, the entire unit might need replacing. Furthermore, they do not qualify for the renewable heat incentive (RHI), so this might influence people towards separate PV and thermal panels. New technological developments in multi-junction cells might achieve between 30 and 40 per cent overall efficiency (Fraunhofer, 2014), but this technology is at present too expensive for general use.

6 Solar Thermal

6.1 Importance to the pathway

In 2050, 58TWh of domestic hot water demand is met by solar thermal, which is equivalent to 61 per cent of the total domestic hot water demand in the pathway.

6.2 Resource

There is good generation potential across the UK as long as optimum positioning is employed, but solar thermal is less suitable in densely populated locations due to shading problems and small roof area per dwelling (EST, 2014b).

6.3 Sources of technology, supply chain, and expertise

Solar thermal collectors take the form of flat plates or evacuated tubes. Although flat plates are cheaper per area evacuated tubes achieve higher temperatures and gather more heat overall. There is some manufacturing in the UK but imports are high. Around half the cost of a system (£3000 to £6000) lies with installation unless a DIY system (£1500 to £2500 retail) is installed (REH, 2014). The skills needed for installation are largely the same as for domestic plumbing and heating systems but with some specialist training.

6.4 Geographical location

UK solar irradiation varies by +/-10 per cent across the country, with lower values in northern Scotland and higher in southern England (Burnett, 2014).

6.5 Grid connection

Solar thermal systems do not consume or use significant amounts of electricity and therefore do not have grid connection problems, but do rely on the availability of the grid to run auxiliary and control systems such as motorised valves and water pumps (STA, 2014).

6.6 Build rate of solar thermal

The 58TWh of solar heat in 2050 represents almost 30 million solar systems, each of 2kW thermal rating. The build rates are around 0.5 million systems per year from 2010 to 2020 rising to almost 1 million per year by 2050. This is a realistic rate given that the average solar PV installation rate in 2012 was about 0.5 million schemes per year (assuming 2kW per system).

6.7 Issues and barriers

A domestic solar thermal installation can only provide around half of annual hot water demand. Similarly, they are not beneficial for use with electric showers, washing machines or dishwashers if they take cold-feed only or with most combi-boilers (other than those which take pre-heated water). The sizing of systems depends upon number of occupants of a house but a hot water cylinder (or ideally a thermal store) double the size of a standard cylinder with adequate capacity and insulation is required. Behavioural issues determine whether households will achieve the full potential savings therefore education of householders and installers is crucial (training fund announced as part of the domestic RHI is a step towards improving installers' skills). Given limited amount of roof space a balance needs to be sought between solar thermal and PV panels. Circumstantial evidence suggests that PV has been displacing solar thermal since 2010 due to the influence of FiTs (EST, 2011).

7 Wind

7.1 Importance to the pathway

Onshore and offshore wind generation are the second and third largest contributors to the total electricity supply in the Thousand Flowers pathway. In 2050, there is 20.5GW of onshore (52.6TWh) and 8.41GW of offshore (31.5TWh), corresponding to 25.6 per cent of all generation. All offshore wind generation is assumed to be in the form of large-scale wind farms, whereas only a quarter of onshore wind is in the form of large-scale wind farms. The remaining three quarters of onshore wind lies in distributed generation at domestic, community, agricultural, and industrial sites.

7.2 Resource

The UK wind resource is very large and mostly offshore with some onshore Scottish resource. However, the variability of wind power makes it difficult to utilise within the UK electricity grid.

7.3 Costs and benefits

Limited economic benefit will accrue to the UK as the majority of manufacturing takes place abroad and the largest wind turbine manufacturers are not UK owned (OffshoreWind.biz, 2014 and Bloomberg, 2014). However, wind is the most mature and technologically proven of the renewable generation technologies and is the least carbon-emitting form of generation apart from nuclear, which has much longer lead times.

7.4 Source of technology, supply chain, and expertise

It is likely that most parts of most wind turbines will be imported but there is a growing UK wind turbine manufacturing capability. The most likely components to be made in the UK are large components not easily transported long distances: rotor blades, nacelles, towers and jackets (lattice structure foundations) of offshore turbines (Areva, 2012, Guardian, 2012, Siemens, 2014, Greenporthull, 2014). There are opportunities to build upon other marine industries' expertise and using existing ports and re-skilling workers for manufacture, construction, operation, and maintenance (RenewableUK, 2014). All types of engineers are needed for the various forms of ocean energy (UK Government, 2013, Scottish Government, 2011, RenewableUK, 2013).

The availability of wind turbines and of specialist vessels (e.g. jack-up barges) could be key constraints on the rate of wind power development as international demand increases (Crown Estate, 2014). Specialist vessels are a key subject of concern to the industry (ACI 2014).

7.5 Geographical location

7.5.1 Onshore wind

The economics of wind power are dominated by the availability of the resource (proportional to the cube of wind speed), economies of scale (size of turbines), and the cost of grid connection. Wind farms need a large land area but only occupy a small fraction of that area with their towers leaving the majority available for recreation, biodiversity, and agriculture. Obstacles (e.g. built-up areas, trees) are to be avoided as they reduce the average wind speed and create turbulence that can increase stresses on turbines and reduce reliability. Turbulence also causes rapid and frequent changes in wind direction that are difficult for most turbines to respond to. Visual intrusion, safety, noise (both audible and very low frequency), and shadow flicker are also important constraints on the siting and planning approval of wind farms (Dept. of Communities and Local Government, 2013).

Wind speeds are typically higher in the west of the UK and on high ground (ETSU, 1999 and DECC, 2014); however, localised effects are a significant factor.

Turbines are not recommended for installation on buildings for all the above reasons but also because of noise and vibration transmitted through the fabric of the building and danger of falling debris in the case of failure. The Warwick Wind Trial study found that the performance of wind turbines in the urban environment was particularly poor³.

7.5.2 Offshore wind

Areas suitable for offshore wind farms (Crown Estate, 2014 and Barnes, 2011) are tightly prescribed by the government after consultation with all stakeholders and considering human activities and environmental factors including seabed geology, shipping lanes, dredging areas, fishing, radar interference, existing pipelines and cables, and visual impact.

Areas of seabed off the coast of England and Wales have been leased to developers in rounds 1, 2, and 3, each progressively larger, further from shore, and in deeper waters. Round 1 is almost complete with a generating capacity of 1.5GW at 18 sites, round 2 will add another 7GW and round 3 will add a maximum of another 31GW. In addition to these, areas have been identified off the coast of Scotland for 5GW and others off Northern Ireland yet to be identified. Potential for further distances offshore is currently limited by water depth and due to connection costs the economics are better close to shore and close to centres of population.

7.6 Grid connection

Grid connection costs and/or availability are sometimes the limiting factor in the viability of wind farms. The visual intrusion of grid connections (substations and overhead wires where used) can sometimes be an issue, as these also need planning approval. Technically, grid connections present a significant risk to wind farm developments, especially offshore, because it is a single point of failure (Hodder 2014 and Barnes, 2011).

Some turbines are being developed to add synthetic inertia to the grid. This helps in frequency control by making a wind turbine behave more like a traditional generator (Lei, 2013 and Gonzalez-Longatt, 2012).

7.7 Build rates

Thousand Flowers has an installed capacity of onshore wind of 20.5GW by 2050. The build rate reaches a maximum of 800MW/year in 2015, dropping to just under 350MW/year between 2025 and 2050. The capacity of offshore wind is just 8.42GW by 2050 representing less than 20 per cent of the potential of allocated sea areas. The build rate reaches a maximum of 680MW/year in 2020, dropping thereafter to 93MW/year and rising again to 140MW/year between 2040 and 2050.

7.8 Issues and barriers

In addition to the barriers identified above, wind power development faces the following challenges:

7.8.1 Generic issues

Wind turbines can have an impact on wildlife – principally the impact of migration routes of birds and bats. RSPB are broadly in favour of wind power, on the grounds that not responding to climate change will be a greater threat (RSPB, 2014).

³ <http://www.warwickwindtrials.org.uk/2.html>

7.8.2 Onshore wind

Some people display opposition to wind power, usually citing intermittent production, visual appearance and noise but community ownership can be more acceptable than a top-down approach (Devine-Wright, 2005, Warren, 2010). However, lack of access to specialist knowledge and limited availability of finance can be barriers to community-scale wind (see Part II).

7.8.3 Offshore wind

The biggest barrier to further expansion of offshore wind is the inaccessible nature of the locations and the impact this has on installation, maintenance, and grid connection all driving up costs. Reliability is also an issue in terms of component failure and downtime for maintenance made worse by having to wait for suitable transport and a weather window.

8 Tidal

8.1 Importance to the pathway

In 2050 there is 8.9GW of tidal capacity generating 18.75TWh, which represents 5.72 per cent of total generation. Tidal generation is a small contributor in the Thousand Flowers pathway in terms of meeting demand but contributes to the decarbonisation of the UK generation mix. A steady build rate is witnessed for tidal energy consistent with tidal stream turbines, reaching a maximum build rate of 566MW per year. The majority of tidal energy growth is witnessed between 2020 and 2035.

8.2 Resource and geographical location

There are limited tidal resources in the UK, although there are strong resources in specific locations (Severn estuary in particular). It was estimated that a total of 20.6TWh (Carbon Trust, 2011) per year could practically be extracted from the 30 key tidal stream sites in the UK. This form of generation needs a tidal height difference of at least 7m to be economic (OEC, 2014). The world's largest tidal power scheme, La Rance, has an average range of 8m (BHA, 2009). Potential sites in the UK are the Bristol Channel, the Irish Sea, the Wash, the Eastern English Channel and the Channel Islands (BERR, 2008).

8.3 Source of technology, supply chain, and expertise

The UK is one of the world leaders in tidal stream technologies with unparalleled energy testing and research infrastructure due to strong funding measures which have led to new prototypes being installed (European Marine Energy Centre, 2014). There is potential to develop a manufacturing basis for both tidal and wave energy in the UK with adequate support which could help revive a declining domestic manufacturing sector. Co-operation across all ocean energy (offshore wind, wave, and tidal) is crucial to stimulate growth, particularly in supply of vessels and port access in order to avoid competition. Tidal and wave energy projects will have to compete with large companies with more attractive projects and are thus likely to miss out thereby impeding their deployment. Suitable vessel/equipment stock needs to be in place to this allow the entire sector to flourish (Crown Estate, 2014).

A similar learning curve will be experienced to that of offshore wind, in installation, operation, and maintenance activities. Expertise gained during recent offshore wind projects needs to be expanded to support future wind, wave, and tidal projects. Investment and training programs will be required to upgrade the offshore sector to support the growth in all ocean energy. This should be addressed in the near term in order to avoid a delay in availability of skilled workers (RenewableUK, 2013).

8.4 Grid connection

Similar to offshore wind and wave energy, resource is often near remote, weak distribution networks, which will struggle to maintain steady state voltage control, limiting the amount of power the grid can handle in these areas. Consequently, any tidal project will likely require upgrade of the local network. Tidal stream turbines require undersea cables which could prove prohibitively expensive unless resource is particularly significant.

8.5 Issues and barriers

Tidal stream energy is a proven technology but every site has different characteristics making tidal stream installations bespoke. This makes it challenging to secure funding as modular approaches are

all but impossible. This is compounded by the many competing concepts in development, proving difficult to select winning concepts at an early stage.

Detailed impacts assessments are required to establish likely consequences; potential environmental impact on migratory fish, marine mammals, and wading birds (NERC 2013, 2013a and 2013b). Furthermore, there may be a potential commercial impact on the fishing industry depending on location. Mitigation programmes may be needed to limit impact of this technology e.g. increased sediment due to reduced flows upstream will increase the need for dredging to maintain port access (Parsons Brinckerhoff, 2010). Initial indications are that environmental impacts of tidal power are acceptable (Royal Haskoning, 2012 and Robins, 2013).

8.6 Costs and benefits

Good economic benefits are to be experienced in the UK should it maintain its lead in this sector – particularly growth in jobs (often in areas of under-utilised ports). However, the environmental impacts of tidal devices (and wave energy devices) are still largely unknown and will have to be monitored carefully during the growth of this sector. This could impede growth initially while regulatory bodies adapt, and adequate data is collected to fill this information gap.

Tidal stream power is inherently predictable, providing a reliable, set amount of power making it an attractive form of generation for grid management. Unfortunately, its impact on peak demand is minimal, as peak demand and peak tide do not necessarily coincide.

9 Wave

9.1 Importance to the pathway

In 2050 there is 2.12GW of wave capacity generating 5.26TWh, which represents 1.60 per cent of total generation. A small contributor to the pathway, its intermittent nature (albeit to a lesser extent than wind) will have an effect on system operation.

9.2 Source of technology, supply chain, and expertise

Since the 1970s oil crisis, the UK has been a leader in the development of wave energy technology and would stand to reap great economic benefit if it maintains its lead in the field. However, a similar leadership in wind generation technology was squandered, and overcome by cheaper imports. Similar supply chains and expertise will be required by wave energy as by all ocean energy as already detailed in the Tidal archetype section.

9.3 Resource and geographical location

The UK benefits from high wave energy resources with the largest resources located in SW England and Scotland, away from demand centres and often where the grid is at its weakest (BERR, 2008).

9.4 Grid connections

Grid connection will prove challenging and expensive for these offshore projects as greater resources are to be found in deeper waters (BERR, 2008) along the UK coast in remote locations with often weak distribution networks. Any wave energy project will therefore require upgrade of the local distribution/transmission network. A balance will need to be struck between potential wave resource, challenge of grid connection, and maintenance when selecting suitable locations.

9.5 Build rate

Build rates for wave power starts at 127MW/year between 2015 and 2020, remaining constant until 2035 when the wave power build rate drops to zero. This break in installation will give the technology time to gain extensive operational experience.

9.6 Issues and barriers

Despite some clear economic benefits to the UK wave generators have remained an immature technology with full scale prototypes only recently being deployed. Joint partnerships with the offshore wind and tidal energy industries may help reduce costs associated with installation and help create more certainty for manufacturing companies involved (and may help lower those costs also). Installations may become physical barriers in the shipping and fishing industries and cause negative economic impact as well as having a potential impact on marine life so need to be sited carefully and monitored closely (NERC 2013, 2013a and 2013b). The full environmental impact of wave energy is largely unknown due to lack of large scale installations to date.

9.7 Costs and benefits

The wave generation industry is already a contributor to UK economy as prototypes are developed. Should the UK maintain its lead, there is a large export potential to countries with high wave resources. Furthermore, penetration of this technology will help decarbonise the UK electricity sector. As wave patterns are more predictable than wind (EPRI, 2005), generation can be predicted a

number of days in advance. Because wave power is not very well correlated with wind power, a combination of the two promises a more reliable renewable energy supply (Fusco, 2010). However, better numerical modelling and superior wave resource data will be required to help assist system integration.

10 Vehicles

10.1 Importance to the pathway

With high levels of intermittent renewable generation in the Thousand Flowers pathway (wind, wave, tidal, and solar generation makes up 37.7 per cent of final electricity generation) electric and hybrid vehicles offer essential balancing services alongside traditional storage to the system.

The transport sector electricity use was derived from the DECC 2050 Pathways Calculator with behaviour level 4 and electrification level 4 and are as follows:

TRANSPORT	Electricity Demand (TWh) 2050 (if data not available, taken 2045)
Electric rail (non-traction)	unknown
Electric rail (freight)	Unknown
Electric rail (passenger)	5.7
Electric buses	14.6
Electric cars (FCV)	12.0
Electric cars (PHEV)[5]	10.2
Electric cars (EV)[6]	37.4
Total electric cars	59.6
Total electric transport	65.3

Electricity used in transportation was derived from the following:

1. Electric buses – from the DECC calculator, under level 4, a radical shift occurs such that public transport and cycling account for 36 per cent of all distance travelled by 2050 and travel by car as a driver or passenger accounts for 62 per cent. This means that bus demand (passenger miles) would be over 3.3 times higher, with implied average of 18 passengers per bus. The majority of the surface passenger transport system is electrified apart from buses, which have a roughly equal share of EVs and conventional hybridisation, potentially using alternative fuels where possible. The last conventional diesel buses are replaced by 2030.
2. Electric rail (domestic passenger and freight) – The whole network is electric by 2050.
3. There is a five per cent reduction in total distance travelled in 2050 reflecting a combination of factors including some long trips being replaced by teleconferencing, a shortening of trips if people shop or undertake recreational activities more locally, and opportunities to work from home.
4. Passenger cars are entirely EVs or powered by a breakthrough in fuel cell technology. This assumes significant reductions in battery costs, hydrogen technology costs, and the availability of infrastructure to support such vehicles. Internal combustion engine (ICE) light duty vehicles are completely removed from the market. By 2050, around 80 per cent of passenger car distance is powered by electricity, with the remainder accounted for by fuel cells (which could be acting as the range extender in PHEVs rather than an ICE range extender as in other plug-ins).

10.2 Connection

At a domestic scale, the most common electric vehicle would be connected at 13A, 230V. At a community-scale, type of connection point will vary from 13A, 230V to 80A, 415V. Currently, there

are around 1500 charging points already installed across the UK⁴. Depending on the battery capacity the charging period will vary. A typical charging period for a standard full electric vehicle would be around 3.5 to 4 hours. The impact of EVs on the distribution grid depends on three factors; the amount of energy needed to charge the battery, the time to charge, and charging power (ICL and ENA, 2010). If the vehicle charging occurs when existing domestic load has its peak value, it is possible to overload the distribution grid, either by reducing the voltage too much or by exceeding the thermal limit of lines (Pudjianto, 2013). EVs provide a vital source of electricity storage for the UK system (Aunedi, 2013). In the event that all registered cars in UK (around 34 million in 2008) were exchanged for EVs, the available storage capacity on the national scale could be in the order of 516GWh⁵.

10.3 Source of technology, supply chain, and expertise

In terms of expertise the UK is falling behind. The Nissan Leaf and the Toyota Prius have successfully dominated the global EV market with German car manufacturers such as Volkswagen and BMW, recently launching their own electric vehicles whilst French and Spanish brands have done so ahead of the Germans. UK car manufactures have shown huge interests in launching electric vehicles, however, so far, only Jaguar Land Rover have released their prototype full electric vehicle. There is much British expertise in battery and fuel cell technologies; however, it is still likely that batteries will be cheaply imported due to lower manufacturing cost, as EVs move from niche to the mainstream (Element Energy 2012).

10.4 Geographical location

EV charging facilities can usually be found in town centres, on-street, in Council-owned car parks, retail parks, and shopping centres. Major cities, such as London⁶, Bath, Birmingham, and Newcastle (Newcastle University, 2013) have already installed numerous EV charging points. There are already more than 1,500 public charging points across country in anticipation of the growth in this area.

10.5 Issues, barriers and benefits

Grid integration of EVs might cause power quality issues for DNOs, such as voltage deviation (Mehmedalic, 2013), and voltage and current harmonics (Rasmussen, 2014). Also, the impact on the distribution network assets mean upgrades or reinforcements are necessary if the EV take-up reaches a certain point (ICL and ENA, 2010). Only when grid carbon intensity reduces will EVs be most effective as a carbon reduction tool, but infrastructure is needed sooner. In addition, the potential driving range of vehicles, combined with long charging periods, will be a possible source of anxiety for drivers (Bunzeck, 2011). Electric charging costs are much less than traditional fuel costs and the UK government's incentive scheme offers a £5k subsidy for buying an EV help to reduce initial outlay and running costs for owners. Also, EVs have additional environmental benefits such as lower air pollution and noise pollution (Hawkins, 2013).

⁴ Charge your car, website: <http://chargeyourcar.org.uk/recharging/>

⁵ Assuming 20kWh battery capacity, 80 per cent available capacity and the vehicle being parked 95 per cent of the time on average. This figure excludes the losses during charging and the battery ageing.

⁶ Source London, www.sourcelondon.net.

11 Heat pumps and air conditioning

11.1 Importance to the pathway

By 2050 just over 10 million of the UK's 35 million homes will have ground source heat pumps installed with 6.7 million installed in existing buildings and 3.4 million in new builds. These supply space and hot water heating to the amount of 28.6TWh and 9.4TWh respectively. Thus, ground source heat pumps are responsible for meeting 30.9 per cent of space heating demand and 10.9 per cent of hot water demand in domestic properties making them a key technology.

11.2 Source of technology, supply chain, and expertise

Ground source heat pumps are a proven technology showing growth across the EU with most heat pumps manufactured in the UK currently being exported. Therefore, manufacturing expertise is already present to supply future increase in uptake as shown in the Thousand Flowers pathway (EHPA, 2013).

11.3 Geographical location

Ground source heat pumps are more appropriate where there is sufficient outdoor space to lay underground pipes, otherwise deep (and expensive) boreholes will be needed. They are also more beneficial when they are replacing oil or LPG heating rather than gas (IEA, 2010)

11.4 Grid connection

Undiversified and aggregated loads from heat pumps have the potential to overload the low voltage distribution network or cause voltage dips. This can be mitigated, however, by adding energy storage (buffer tanks) to heat pump systems or using demand side management to shift the timing of heat pumps. Storage systems for heat pumps can consist of building fabric, hot water, cold water, ice, and other phase-change materials (PCMs) (Delta-EE, 2013).

11.5 Issues and barriers

Ground source and air source heat pumps have some issues in common – however, please note that there are no air source heat pumps in the Thousand Flowers pathway. Information was taken from (EST, 2013).

11.5.1 Lower temperature

The temperature of water from the majority of heat pumps is lower than from a gas boiler (HPA, 2015a) so they are better suited to under floor heating than radiators (unless the size of radiators is increased).

11.5.2 Learning curve for householders

Households need to learn how to use the heat pump controls effectively to derive optimum performance from the technology. Ideally, heat pumps need to be supplying the majority of demand for maximum efficiency (HPA, 2015b). This could be of concern to householders if they perceive that the constant heating equates to higher bills.

11.5.3 Upskilling of heating engineers

Heating engineers in the UK need to further develop their skills and knowledge in the installation and maintenance of heat pumps to meet the potential increase in demand.

11.5.4 Low-carbon

The carbon footprint of electricity generation has a significant impact on the CO₂ emission of heat pumps – whether heat pumps are a low-carbon technology depends highly on the fuel mix used in the electricity grid.

11.5.5 Performance

Performance is wide ranging and does not always achieve an adequate level. Current RHI standards require a benchmark coefficient of performance of 2.5 to qualify as a renewable source under the EU RES directive and to qualify for payments. In an Energy Saving Trust study, none of the ASHPs tested reached this level until remedial action had been taken and even then 40 per cent of systems still under performed, although more recent installations performed better

11.5.6 Coolant leakage and disposal

Heat pumps contain refrigerants, themselves greenhouse gases – for example HFCs which are 1600 times more potent than CO₂. Leakage of refrigerant will therefore have an impact although this must be balanced against the fact that modern heat pumps are hermetically sealed and contain only ½ litre of refrigerant, which is required to be recovered at the end of its lifecycle(Pineau, 2013)

1.1.1.1 Specific issues for ground source heat pumps

Due to installation costs, ground source heat pumps are best combined with building work or new developments rather than retrofit. The ground must be accessible to diggers – not too wet, stony, or inside an inaccessible back garden. Ground loop systems can be either shallow (1.2 to 2m deep) in the ground, which requires a large area of land, or a borehole.

Where land area allows, a well-insulated, medium-sized house requires 400 to 500 square metres of ground (40 to 50m of double trench, 5 metres apart). Since houses with large gardens tend to be old houses with poorer thermal performance, this is likely to be a barrier, until they are retrofitted to a much higher standard of insulation. Where there is insufficient space, then deep (up to 100m) boreholes are required, which are expensive and invasive (EST, 2014).

12 Micro-Hydro

12.1 Importance to the pathway

Micro-hydro is a small player in the Thousand Flowers pathway and while it does increase from 1.2GW in 2010 to 1.7GW by 2020 it does not see significant expansion beyond this. However, as an established and mature technology, it is one of the early movers of the micro-generation take up. Many of the most cost effective sites have been developed by 2020 after which community energy schemes increasingly favour other technologies and schemes e.g. CHP.

12.2 Resource and geographical location

There is limited resource currently not used that is economically viable. There is said to be only 1-2 per cent of UK current generation capacity left for viable hydro (DECC, 2013b), however the level of viability may change if electricity costs increase. In these cases, however, environmental concerns may be greater and resources are often not near demand or grid connections (BHA, 2010). The best sites have steep hills ('head') and fast flowing water (BHA, 2012). Old watermill sites are also good indicators of micro-hydro potential and although the head might be lower, the flow rate is high and the flow more constant and reliable than at higher, steeper sites.

12.3 Source of technology, supply chain, and expertise

Micro-hydro is a mature technology; there are a significant number of operational schemes in the UK currently (BHA, 2011).

12.4 Issues and barriers

There is a 'circular nature' of the planning process with landowners needing detailed plans before they will give consent but the preparation of plans needs funding and funding is generally only given if the landowners' permission is in place. With land ownership there also comes the need to ensure rights of access to rivers and adjoining land for installation of plant alongside access to the electricity distribution grid to export surplus power and qualify for FiTs.

Community generation schemes rely heavily on skilled volunteers to get the project started – as with any community generation scheme, and there can be large upfront costs in assessing feasibility of a site and providing the legal structure for community shared ownership. Although each micro-hydro scheme is different, and so there is little opportunity for findings from one project being re-used elsewhere, the approach, skills, and documentation needed can.

There is a perception that there is a negative impact on fish populations with these schemes which may or may not be the case depending on type of turbine and so there may be the need for protective screening or a fish pass on migratory routes (SNIFFER, 2011). Flood risks in areas may also increase and therefore careful design and management is needed (BHA, 2012). The Environment Agency's approval checks that this is the case, as does the need for planning permission.

12.5 Costs and benefits

The price of a micro-hydro system will vary widely dependent on size of system and the associated building works. Although capital costs for hydropower are high, installations last for decades and low head installations can generate renewable energy 24 hours a day and are currently eligible for FiTs.

13 Waste heat

13.1 Importance to the pathway

In Thousand Flowers, 6.58 per cent of UK households heating requirement is met by waste heat via district heating from power stations by 2050⁷. This is equivalent to meeting 2.4 million out of 35 million homes entire heating needs by waste heat (Barton, 2013a).

13.2 Resource

Any demand for low grade heat could be met with a nearby higher grade surplus waste heat – common sources of waste heat are power plants and industry. Heat is a substantial co-product of electricity generation. After the June 5th 2014 (EU Directive, 2012) new and refurbished power plants will have to make use of waste heat unless they can prove it would be uneconomical. Nuclear plants make a good source of waste heat due to high availability. In contrast, the coal and gas plants in Thousand Flowers are load following (Barton, 2013b), with low capacity factors, which would suggest they would be less suitable for providing heat exclusively to a district heating system.

In the Thousand Flowers pathway, there is no mention of waste heat recovery from industrial units. However, there is significant potential that should be exploited. Analysis of this sector estimates that overall surplus heat that was technically recoverable using currently available heat recovery technologies was estimated at 52PJ/yr, leading to a saving of 2.2MtCO₂e/yr in comparison to supplying the energy outputs in a conventional manner (Hammond, 2014). A report completed for DECC, suggests a potential for industrial heat recovery in the UK in the range of 5TWh/yr to 28TWh/yr (a 6TWh/yr commercial potential and a 28 TWh/yr district heat production potential) (Elementenergy, 2014).

13.3 Source of technology, supply chain, and expertise

The UK is currently not set up for this type of energy system and will have serious infrastructure needs. In practice, most potential will be for new building developments near sites of high heat waste. Supply chain needs will be similar to district heating as detailed in the Combined Heat and Power(CHP) section. There are many heat recovery technologies available to allow for a variety of applications, widening the scope of potential exploitation of waste heat, however, expertise is lacking due to lack of experience of such projects in the UK (DECC, 2013).

13.4 Grid connection

To take advantage of waste heat, extensive district heating networks are required to deliver heat to the point of demand. Such a system would likely operate on at least a dual heat source basis (IEA, 2014); primarily waste heat when available, which could then be complemented with an alternative to supply the shortfall when required. Suitable examples are deep bore hole heat pumps or a heat led biomass CHP unit. Alternatively, systems could benefit from local heat generation during periods of heat deficit such as in-home heat pumps or Stirling engines. Physical connection details are the same as that for community-scale CHP at the local level.

13.5 Geographical location

Current power stations locations and industrial areas are large resources for utilisation. Below is a map of potential waste heat sources based on analysis of industrial sector only (Figure 1).

⁷ Demand side spreadsheet

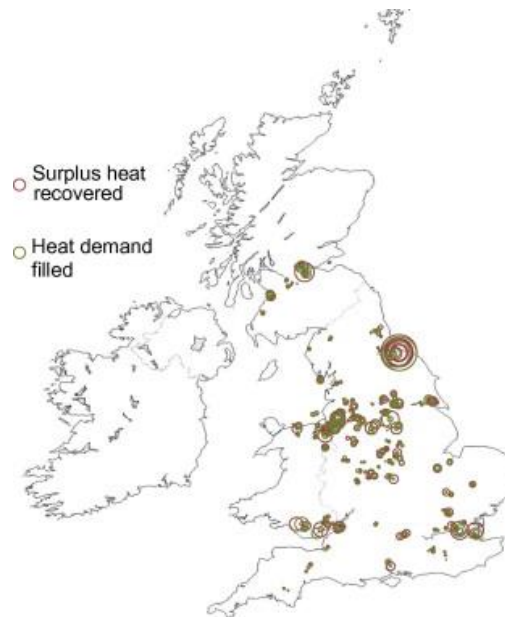


Figure 1 Location of surplus heat from industry **Error! Bookmark not defined.** (Hammond, 2014)

13.6 Build rates

Waste heat recovery from power stations is first introduced in 2020, meeting a demand of 46.22TWh of heat⁸. This grows to a peak of 104.55TWh of heat in 2040. As a result of a reduction in space and water heating demand, this demand reduces to 98.63TWh in 2050. To supply this demand would suggest a large increase in district heating infrastructure between 2020 and 2040. Such build rates may not prove reasonable in addition to infrastructure needs for community CHP.

13.7 Issues and barriers

A heat network and heat market for trading in heat will need to be established in order to drive the use of surplus heat (Hammond, 2014). The wider use of district heating systems will also be needed to transport heat from industrial sites to other users on a national scale. Waste heat exploitation faces similar barriers to many energy efficiency projects in manufacturing, which include lack of capital and competition with production orientated projects.

Policy uncertainty is a large barrier for this technology as it would require strong support for such a long term investment in infrastructure. Equally, lack of information, staff time, and expertise to explore opportunities will impede such projects from reaching development (Thornley and Walsh, 2010).

13.8 Costs and benefits

Heat recovery technologies are capital intensive and the economics are highly dependent on the quality of the heat source. The lower estimate of recovery heat of 5TWh/yr from industry refers to projects which currently prove commercially viable (Elemantenergy, 2014). Waste heat recovery can help to greatly reduce the operating energy cost of an industrial unit's energy costs. This is particularly key to maintaining the competitiveness of UK industrial sectors particularly as such costs are expected to rise in coming years.

⁸ Demand side spreadsheet

14 Summary

The exploration of each technological archetype within the Thousand Flowers pathway has enabled an analysis of build rates, issues, and barriers across technologies. The technological feasibility of the main assumptions has been established, allowing potential arising issues to be identified. Looking across the archetypes a number of themes appear. Some of these were explored in the Distributing Power report (RTP Engine Room, 2015), but others that have been identified follow here.

the Thousand Flowers pathway relies upon on a number of technologies all playing different roles and contributing a small part to the greater whole. Alongside increased numbers of DG the electrical grid must be reinforced, upgraded, and expanded to increase connectivity to allow for remote generation to come online and increase the potential for imports. The demand for engineers and technicians will increase with increased build rates for many DG technologies meaning that with the right apprenticeship and educational programmes the UK could drive the sector. Similarly, the UK has the potential to use current expertise to become world leading experts and manufacturers in a number of generation technologies. There is also a clear need for reliable sources of sustainable biofuels to fuel the multiple technologies that require them within the pathway.

For offshore wind and solar in particular the build rates and installed capacity have the potential to exceed their installed capacities in the pathway. This has the potential to eat into CHP production and affect the viability of this important balancing technology at the local scale. Finally, and most importantly, the Thousand Flowers system requires great change and adaptability of all its participants. This means that there has to be sufficient drivers for change to overcome all barriers and allow the pathway to proceed.

Distributed generation is gaining momentum across Europe, particularly in countries such as Germany and Denmark. Currently, less than 1 % of UK electricity demand is met by community- or local authority-owned distributed electricity generation. The Thousand Flowers pathway represents an increase to 50% market share by 2050 which has been shown, whilst challenging, to be technologically feasible. These technology archetypes map the main facets of the most critical technologies for this pathway, allowing this type of future to be visualised in greater detail than ever before. Greatest technological challenges and areas of weakness in this energy transition have been unpicked and scrutinised here. This output endeavours to alleviate some of the uncertainty and complexity associated with the increasing penetration of decentralised generation in the UK.

15 References

- (AEA, 2011) - AEA (2011) *UK and Global Bioenergy Resource – Final Report*. DECC ED 56029. Issue 2 - Final March 2011. AEA Technology Plc.
- (ACI, 2014) - Conference: Active Communications International 2014, 'Developing Specialist Wind Vessels Summit 2014', 9th and 10th April 2014 Aberdeen URL: <http://www.wplgroup.com/aci/conferences/eu-mow1.asp>
- (Areva, 2012) - Web site: Areva 2012, 'Offshore Wind: AREVA to localize in Scotland and completes robust industrial plan in Europe', Press release 19th November 2012, accessed 9th October 2014 URL: <http://www.areva.com/EN/news-9602/offshore-wind-areva-to-localize-in-scotland-and-completes-robust-industrial-plan-in-europe.html#>
- (Aunedi, 2013) - M. Aunedi, G. Strbac, "Efficient System Integration of Wind Generation through Smart Charging of Electric Vehicles", 8th International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER), Monte Carlo, March 2013. DOI: 10.1109/EVER.2013.6521630.
- (Barnacle, 2013) - Barnacle, M, Robertson, E, Galloway, S, Barton, J, and Ault, G, Modelling generation and infrastructure requirements for transition pathways. Energy Policy, 2013. 52(0): p. 60-75.
- (Barnes, 2011) - Mike Barnes, 'Connecting offshore wind farms to the onshore grid', presentation to Supergen Wind project 25th March 2011, accessed 10th October 2014 URL: http://www.supergen-wind.org.uk/docs/presentations/2011-03-25_Session7_MikeBarne_.pdf
- (Barton, 2013a) - Barton, J, Huang, S, Infield, D, Leach, M, Ogunkunle, D, Torriti, J, and Thomson, M, The evolution of electricity demand and the role for demand side participation, in buildings and transport. Energy Policy, 2013. 52(0): p. 85-102.
- (Barton, 2013b) - Barton et al. (2013), Realising Transition Pathways Working Paper 2013/5
- (BERR, 2008) - BERR, 'Atlas of UK Marine Renewable Energy Resources', March 2008, accessed 10th October 2014
- (BERR, 2013) - Digest of United Kingdom Energy Statistics 2013. BERR.
- (BHA, 2009) - British Hydropower Association 2009, 'La Rance Tidal Power Plant', accessed 10th October 2014 URL: www.british-hydro.org/downloads/La%20Rance-BHA-Oct%202009.pdf
- (BHA, 2010) - British Hydropower Association and IT Power, "England and Wales Hydropower Resource Assessment", October 2010. Available at: <http://www.british-hydro.org/UK%20Hydro%20Resource/England%20and%20Wales%20Resource%20Study%20Oct%202010.pdf>.
- (BHA, 2011) - British Hydropower Association, "Britain's Hydropower Installations", October 2011. Available at: http://www.british-hydro.org/downloads/UK_Installations/BHA%202011.pdf.

(BHA, 2012) - British Hydropower Association, "A Guide to UK Mini-Hydro Developments", October 2012. Available at: http://www.british-hydro.org/Useful_Information/A%20Guide%20to%20UK%20mini-hydro%20development%20v3.pdf.

(Bloomberg, 2014) = Web site: Bloomberg, 'Vestas Regains Wind Turbine Market Share Lead in Navigant Study', Alex Morales Mar 26, 2014, accessed 9th October 2014 URL: <http://www.bloomberg.com/news/2014-03-26/vestas-regains-wind-turbine-market-share-lead-in-navigant-study.html>

(Bunzeck , 2011) - I. Bunzeck, Y. Feenstra, M. Paukovic, "Preferences of potential users of electric cars related to charging - A survey in eight EU countries", Deliverable 3.3 of Grid-for-Vehicles project, March 2011. Available at: http://www.g4v.eu/datas/reports/G4V_WP3_D3_2_social_aspects.pdf.

(Burgess, 2009) – Paul Burgess, "Variation in light intensity at different latitudes and seasons, effects of cloud cover, and the amounts of direct and diffused light", Presentation to Continuous Cover Forestry Group (CCFG) Scientific Meeting 29 September 2009, Westonbirt Arboretum, Gloucestershire.

(Burnett, 2014) - Dougal Burnett, Edward Barbour, Gareth P. Harrison (2014) The UK solar energy resource and the impact of climate change, Renewable energy Renewable Energy 71 (2014) 333e343

(Carbon Trust, 2011) - Black & Veatch Limited for The Carbon Trust, "UK Tidal Current Resource & Economics", June 2011. Available at: http://www.carbontrust.com/media/77264/ctc799_uk_tidal_current_resource_and_economics.pdf

(Clean Air Act, 1993) - Clean Air Act 1993, chapter 11. Available at: <http://www.legislation.gov.uk/ukpga/1993/11/resources> (Accessed: 17 October 2014)

(Crown Estate, 2014) - The Crown Estate 2014 , 'Jack-up vessel optimisation', July 2014 URL: <http://www.thecrownestate.co.uk/media/370242/ei-jack-up-vessel-optimisation.pdf>

(Crown Estate , 2014) - The Crown Estate, 'Leasing Rounds', accessed 10th October 2014 URL: <http://www.thecrownestate.co.uk/energy-and-infrastructure/offshore-wind-energy/working-with-us/leasing-rounds/>

(Dept. of Communities and Local Government, 2013). - Dept. of Communities and Local Government 2013, 'Planning practice guidance for renewable and low carbon energy', July 2013

(Dept. of Communities and Local Government, 2013b) - [Department for Communities and Local Government](http://www.planningportal.gov.uk/uploads/br/domestic_building_services_compliance_guide.pdf) ,Domestic Building Services Compliance Guide, 2013. Available at: http://www.planningportal.gov.uk/uploads/br/domestic_building_services_compliance_guide.pdf Accessed: 17 October 2014)

(DECC, 2012) - DECC, UK Bioenergy Strategy (April 2012) URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48337/5142-bioenergy-strategy-.pdf

(DECC, 2013) - DECC. The Future of Heating: Meeting the Challenge. London, UK: Department of Energy and Climate Change;2013

(DECC, 2013b) - Department of Energy & Climate Change and Environment Agency, *Harnessing hydroelectric power*, <https://www.gov.uk/harnessing-hydroelectric-power>, First Published: 22 January 2013

(DECC, 2014) - DECC 2014, 'Annual mean wind speed map', source: UK wind speed database and BERR, accessed 9th October 2014, URL: <https://restats.decc.gov.uk/cms/annual-mean-wind-speed-map>

(DECC, 2014b) – Web site: “District Heating - International Experience: Copenhagen District Heating System in Denmark, Europe”, DECC, accessed 21th October 2014, URL: <http://chp.decc.gov.uk/cms/district-heating-international-experience>

(Delta-EE, 2013) - Delta Energy and Environment (2014), Heat Pump in Gas Grid https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/341742/Delta-ee_Task_1_UK_Market_Report_-_Final.pdf

(Devine-Wright, 2005) - Patrick Devine-Wright 2005, 'Beyond NIMBYism: towards an Integrated Framework for Understanding Public Perceptions of Wind Energy', Wind Energ. 2005 vol.8 pp.125–139 URL: http://www.ownenergy.net/sites/default/files/images/Devine_Wright_2005.pdf DOI: 10.1002/we.124

(EEG, 2014) : (Erneuerbare-Energien-Gesetz – EEG) German Renewable Energy Sources Act 2014

(Element Energy 2012) - Element Energy, “Cost and performance of EV batteries”, Final report for The Committee on Climate Change, March 2012. Available at: <http://www.element-energy.co.uk>.

(Elementenergy, 2014) - Elementenergy &DECC, The potential for recovering and using surplus heat from industry. 2014.

(EHPA, 2013) - Outlook (2012), European Heat Pump statistics, European Heat pump Association (EHPA) EHPA.org, Accessed July 2013

(EPIA, 2013) 'Global Market Outlook For Photovoltaics 2013-2017', European Photovoltaic Industry Association, Renewable Energy House, Rue d'Arlon 63-67, 1040 Brussels – Belgium, www.epia.org

(EPRI, 2005) - EPRI, 'Final Summary Report, Project Definition Study, Offshore Wave Power Feasibility Demonstration Project', Report: E21 EPRI Global WP 009 – US Rev 2, Author Roger Bedard, 22nd September 2005 URL: http://oceanenergy.epri.com/attachments/wave/reports/009_final_report_rb_rev_2_092205.pdf

(EST, 2011) - Energy Saving Trust (2011) Here comes the sun: a field trial of solar water heating systems <http://www.energysavingtrust.org.uk/Organisations/Technology/Field-trials-and-monitoring/Field-trial-reports/Solar-water-heating-systems-field-trial> Accessed September 2014

(EST, 2013) = Energy Saving Trust (2013),The heat is on: heat pump field trials. <http://www.energysavingtrust.org.uk/Organisations/Technology/Field-trials-and-monitoring/Field-trial-reports/Heat-pump-field-trials>

(EST, 2014) - Energy Saving Trust (2014) Heat pumps: <http://www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/>

(EST, 2014b) - Energy saving Trust (2014) Solar water heating <http://www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Solar-water-heating> Accessed September 2014

(ETSU, 1999) - ETSU for the DTI 1999, 'Wind speed map of the UK: Annual mean wind speed at 25m above ground level (m/s)', accessed 9th October 2014 URL: http://www.esru.strath.ac.uk/EandE/Web_sites/03-04/wind/content/ukwindspeedmap.html

(EU Directive, 2012) - Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, 2012

(European Marine Energy Centre, 2014) - The European Marine Energy Centre Ltd 2014 [1], 'Tidal Developers', 1st August 2014, accessed 13th October 2014, URL: <http://www.emec.org.uk/marine-energy/tidal-developers/>

(FCI, 2014) - Forestry Commission England Information Sheet 7 Domestic Heating with Woodfuel Available at: http://www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/RESOURCES/REF_LIB_RES/PUBLICATIONS/FC-BEC-INFOSHEET07-WOODFUEL.PDF. (Accessed: 17 October 2014)

(Fraunhofer, 2014) – Fraunhofer Institute For Solar Energy Systems ISE, 'Photovoltaics Report', Freiburg, 24 October 2014, www.ise.fraunhofer.de

(Fusco, 2010) - Fusco, F. et al., 'Variability reduction through optimal combination of wind/wave resources – An Irish case study', Energy vol. 35 (2010) pp. 314–325, doi:10.1016/j.energy.2009.09.023

(Guardian, 2012) - Guardian newspaper 2012, 'Areva to open wind turbine factory in Scotland', 19th November 2012, accessed 9th October 2014 URL: <http://www.theguardian.com/environment/2012/nov/19/areva-wind-turbine-factory-scotland>

(Greenporthull, 2014) - Web site: GreenportHull 2014, accessed 9th October 2014 URL: <http://www.greenporthull.co.uk/>

Gonzalez-Longatt, 2012) - Gonzalez-Longatt, F et. al., 'Effects of the Synthetic Inertia from Wind Power on the Total System Inertia after a Frequency Disturbance', IEEE Power and Energy Society Conference and Exposition in Africa: Intelligent Grid Integration of Renewable Energy Resources, July 2012, pp.1-7

(Hammond, 2014) - Hammond, G.P. and J.B. Norman, Heat recovery opportunities in UK industry. Applied Energy, 2014. 116(0): p. 387-397.

(Hawkins, 2013) - T. R. Hawkins, B. Singh, G. Majeau-Bettez, A. Hammer Strømman, "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles", Journal of Industrial Ecology, Volume 17, Issue 1, pages 53–64, February 2013.

(Hodder, 2014) - Jim Hodder, "Driving Forward", Energy engineering, accessed 10th October 2014, URL: http://www.energyengineering.co.uk/latestissue/EE19_PMSS.html

(HPA, 2015a) – Web site: Heat Pump Association 2015, accessed 27th April 2015 URL: <http://www.heatpumps.org.uk/TypesOfHeatPump2.html>

(HPA, 2015b) – Heat Pump Association, Heat Pump Data: Heat Pump Association data sheet No. 1, accessed 27th April 2015, available at <http://www.heatpumps.org.uk/HeatPumpDataSheets.html>

(ICL and ENA, 2010) - Imperial College London and Energy Networks Association, "Benefits of Advanced Smart Metering for Demand Response-Based Control of Distribution Networks", April 2010. Available: www.energynetworks.org.

(IEA, 2010) - IEA (2010), Retrofit heat pumps for buildings: final report. *IEA heat pump programme*. Boras, IEA Heat PumpCentre

(IEA, 2011) - IEA, Combining Bioenergy with CCS, Reporting and Accounting for Negative Emissions under UNFCCC and the Kyoto Protocol. Working Paper. International Energy Agency, Paris (2011)

(IEA, 2014) - IEA, Linking Heat and Electricity Systems: Co-generation and District Heating and Cooling Solutions for a Clean Energy Future, 2014

(IRENA, 2014) – Web site: “Global Atlas for Renewable Energy”, International Renewable Energy Agency, accessed: 21st October 2014. URL: <http://globalatlas.irena.org/Default.aspx?tid=5>

(Jordan and Kurtz, 2012) – Jordan, Dirk; Kurtz, Sarah; ‘Photovoltaic Degradation Rates — An Analytical Review’, *Progress in Photovoltaics*, 21(1) 2013, pp 12-29, DOI: 10.1002/pip.1182. Also Journal Article NREL/JA-5200-51664, June 2012, <http://www.nrel.gov/docs/fy12osti/51664.pdf>

(Lei, 2013) - Wu, Lei; Infield, David G.; ‘Towards an Assessment of Power System Frequency Support From Wind Plant – Modelling Aggregate Inertial Response’, *IEEE Trans. Power Systems* 28(3), Aug. 2013, pp.2283-2291

(Lopes, 2006) - Peas Lopes, J. A., et al. (2006). "Defining control strategies for MicroGrids islanded operation." *Power Systems, IEEE Transactions on* 21(2): 916-924.

(Mayor of London, 2014) – Web site: “London heat Map”, Mayor of London, accessed 21st October 2014, URL: <http://www.londonheatmap.org.uk/Content/About.aspx>

(Mehmedalic, 2013) - J. Mehmedalic, J. Rasmussen, S. Harbo, “Reinforcement Costs in Low-voltage Grids”, Deliverable D4.3 – B2 of Green eMotion project, November 2013. Available at: <http://www.greenemotion-project.eu/dissemination/deliverables-infrastructure-solutions.php>.

(Met Office, 2014) – Web site: “Solar energy”, Met Office, accessed 21st October 2014. URL: <http://www.metoffice.gov.uk/renewables/solar>.

(NERC, 2013) - Natural Environment Research Council, ‘Wave & Tidal Consenting Position Paper Series: Impacts on Fish and Shellfish Ecology’, 7th November 2013 URL: <http://www.renewableuk.com/en/publications/reports.cfm/Impacts-on-Fish-and-Shellfish-Ecology>

(NERC, 2013b) - Natural Environment Research Council, ‘Wave & Tidal Consenting Position Paper Series: Marine Mammal Impacts’, 7th November 2013 URL: <http://www.renewableuk.com/en/publications/reports.cfm/Marine-Mammals-Impacts>

(NERC, 2013c) - Natural Environment Research Council 2013, ‘Wave & Tidal Consenting Position Paper Series: Ornithological Impacts’, 7th November URL: <http://www.renewableuk.com/en/publications/reports.cfm/Ornithological-Impacts>

(Newcastle University, 2013) - Newcastle University, Future Transport Systems, “Switch EV – Final Report”, May 2013. Available: www.futuretransportsystems.co.uk/_diskcache/296-final-report-for-seminar.pdf.

(NNFCC, 2012) - NNFCC (2012), *Domestic Energy Crops; Potential and Constraints Review*. A report for DECC, April 2012, project number 12-021.

(OEC, 2014) - Ocean Energy Council 2014, ‘What is tidal energy?’, accessed 10th October 2014 URL: <http://www.oceanenergycouncil.com/ocean-energy/tidal-energy/>

(OffshoreWind.biz, 2014) - Web site: Offshorewind.biz Business guide, ‘UK: Vestas, GE Lead among Wind Turbine Manufacturers in 2012’, accessed 9th October 2014 URL:

<http://www.offshorewind.biz/2013/04/22/uk-vestas-ge-lead-among-wind-turbine-manufacturers-in-2012/>

(Parsons Brinckerhoff , 2010) - Parsons Brinckerhoff Ltd for DECC 2010, 'SEVERN TIDAL POWER – SEA TOPIC PAPER: Navigation', March 2010, accessed 13th October 2014 URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69908/44._Navigation_-_NTS.pdf

(Pineau, 2013) - Rivière Philippe David Pineau, Pascal Stabatb, Phuong Hoanga, Valérie Archambaulta (2013), Performance analysis of heating systems for low energy houses. Energy and Buildings 65 (2013) 45–54

(Pudjianto, 2013) - D. Pudjianto, P. Djapic, M. Aunedi, C. K. Gan, G. Strbac, S. Huang, D. Infield, "Smart control for minimizing distribution network reinforcement cost due to electrification", Energy Policy, Vol. 52, pp. 76-84, January 2013. DOI: 10.1016/j.enpol.2012.05.021.

(Rasmussen , 2014) - J. Rasmussen, J. A. Bjørn, "EVs' impact on Power Quality related to harmonics", Deliverable D4.3 – A1 of Green eMotion project, January 2014. Available at: <http://www.greenemotion-project.eu/dissemination/deliverables-infrastructure-solutions.php>.

(REF.com, 2014) – Web site: "CIGS drives indium use in solar PV", RenewableEnergyFocus.com. Accessed: 21st October 2014. Available at: <http://www.renewableenergyfocus.com/view/20524/cigs-drives-indium-use-in-solar-pv/>

(REH, 2014) - Renewable Energy Hub (2014), How much does solar energy cost? <http://www.renewableenergyhub.co.uk/how-much-does-solar-thermal-cost.html> Accessed August 2014

(RenewableUK, 2013) - RenewableUK, 'Skills Manifesto: Skills policy recommendations from the wind and marine energy industries', 23rd October 2013 URL: <http://www.renewableuk.com/en/publications/reports.cfm/skills-manifesto>

(RenewableUK, 2014) - RenewableUK, 'Maximising the Value of Marine Energy to the United Kingdom: Marine Energy Programme Board report', February 2014 URL: <http://www.renewableuk.com/en/publications/reports.cfm/Maximising-the-Value-of-Marine-Energy-to-the-UK>

(RenSMART, 2014) – Web site: "PVGIS Solar Map1.0", RenSMART.com, accessed: 21st October 2014. Available at: <http://www.rensmart.com/Weather/PVGISolar>

(Robins, 2013) - Peter E. Robins, 'Influence of tidal energy extraction on fine sediment dynamics', 2nd Oxford Tidal Energy Workshop, 18-19 March 2013, Oxford, UK

(Royal Haskoning , 2012) - Royal Haskoning, 'SEAGEN STRANGFORD LOUGH TIDAL TURBINE GETS ALL-CLEAR FROM ENVIRONMENTAL & SCIENTIFIC STUDIES', 17th January 2012, accessed 13th October 2014 URL: <http://www.royalhaskoning.co.uk/en-gb/News/Pages/Seagen-Tidal-Turbine-Gets-All-Clear-From-Environmental-Scientific-Studies.aspx>

(RSPB, 2014) - RSPB 2014, 'Policy makers: Wind farms', 1st September 2014, accessed 10th October 2014 URL: <http://www.rspb.org.uk/forprofessionals/policy/windfarms/>

(RTP Engine Room, 2015) - Realising Transition Pathways Engine Room (2015). Distributing Power: A transition to a civic energy future. Realising Transition Pathways Research Consortium. Available at:

http://www.realisingtransitionpathways.org.uk/realisingtransitionpathways/news/distributing_power.html

(Shockley, 1961) - Shockley, W. and H. J. Queisser (1961). "Detailed Balance Limit of Efficiency of p-n Junction Solar Cells." Journal of Applied Physics 32(3): 510-519.

(Siemens, 2014) - Web site: Siemens 2014, 'Siemens to build major offshore wind manufacturing site in the UK', accessed 9th October 2014 URL: http://www.siemens.co.uk/en/news_press/index/news_archive/2014/major-uk-offshore-wind-manufacturing-site-to-be-built-by-siemens.htm

(Scottish Government, 2011) - Scottish Government and Skills Development Scotland, 'Skills Investment Plan for the Energy Sector', 2011, accessed 9th October 2014 URL: http://www.offshorewindscotland.org.uk/index.php/building_the_industry/creating_a_skilled_work_force

(SNIFFER, 2011) - Scotland and Northern England Forum for Environmental Research (SNIFFER), "Impact of run-of-river hydro schemes upon fish populations", August 2011. Available at:

(SMA, 2012) - SMA Solar Technology (2012). "PV Grid Integration: Backgrounds, requirements, and SMA solutions, 4th revised edition, last revised: May 2012."

(STA, 2014) - Solar Trade association (2014) Solar heating <http://www.solar-trade.org.uk/solarHeating/howItWorks.cfm> Accessed September 2014

(Thornley and Walsh, 2010) - Dr Patricia Thornley and Dr Conor Walsh, Addressing the barriers to utilisation of low grade heat from the thermal process industries.2010.

(UKHFCA, 2014) : Web site: "The industry", UK Hydrogen and Fuel Cell Industry, Accessed 21st October, 2014, URL: <http://www.ukhfca.co.uk/the-industry/>

(UKERC, 2011) - UKERC(2011), Energy from biomass: the size of the global resource An assessment of the evidence that biomass can make a major contribution to future global energy supply

(UK Government, 2013) - UK Government, 'Offshore Wind Industrial Strategy Summary: Business and Government Action', August 2013, www.official-documents.gov.uk

(VDE-AR-N 4105) - VDE-AR-N 4105: Generators connected to the low-voltage distribution network – Technical requirements for the connection to and parallel operation with low-voltage distribution networks

(Verma, 2011) - V.K. Verma, S. Bram, G. Gauthier, J. De Ruyck, Evaluation of the performance of a multi-fuel domestic boiler with respect to the existing European standard and quality labels: Part-1, Biomass and Bioenergy, Volume 35, Issue 1, January 2011, Pages 80-89, ISSN 0961-9534, <http://dx.doi.org/10.1016/j.biombioe.2010.08.028>.

(Warren, 2010) - Charles Warren 2010, 'Does community ownership affect public attitudes to wind energy? A case study from south-west Scotland', Land Use Policy vol. 27(2) pp.204-213 URL: <http://www.sciencedirect.com/science/article/pii/S0264837709000039> DOI: 10.1016/j.landusepol.2008.12.010

(Welfle, 2014) - Andrew Welfle, Paul Gilbert, Patricia Thornley (2014)Securing a bioenergy future without imports. Energy Policy. 01/2014; 68:1–14.

(Woodcock, 2013) - Woodcock, M. (2013) *South East and London Wood Market Update*. Headline Statistics, Forestry Commission